Some (and Only Some!) Aspects of FAME Data Analysis

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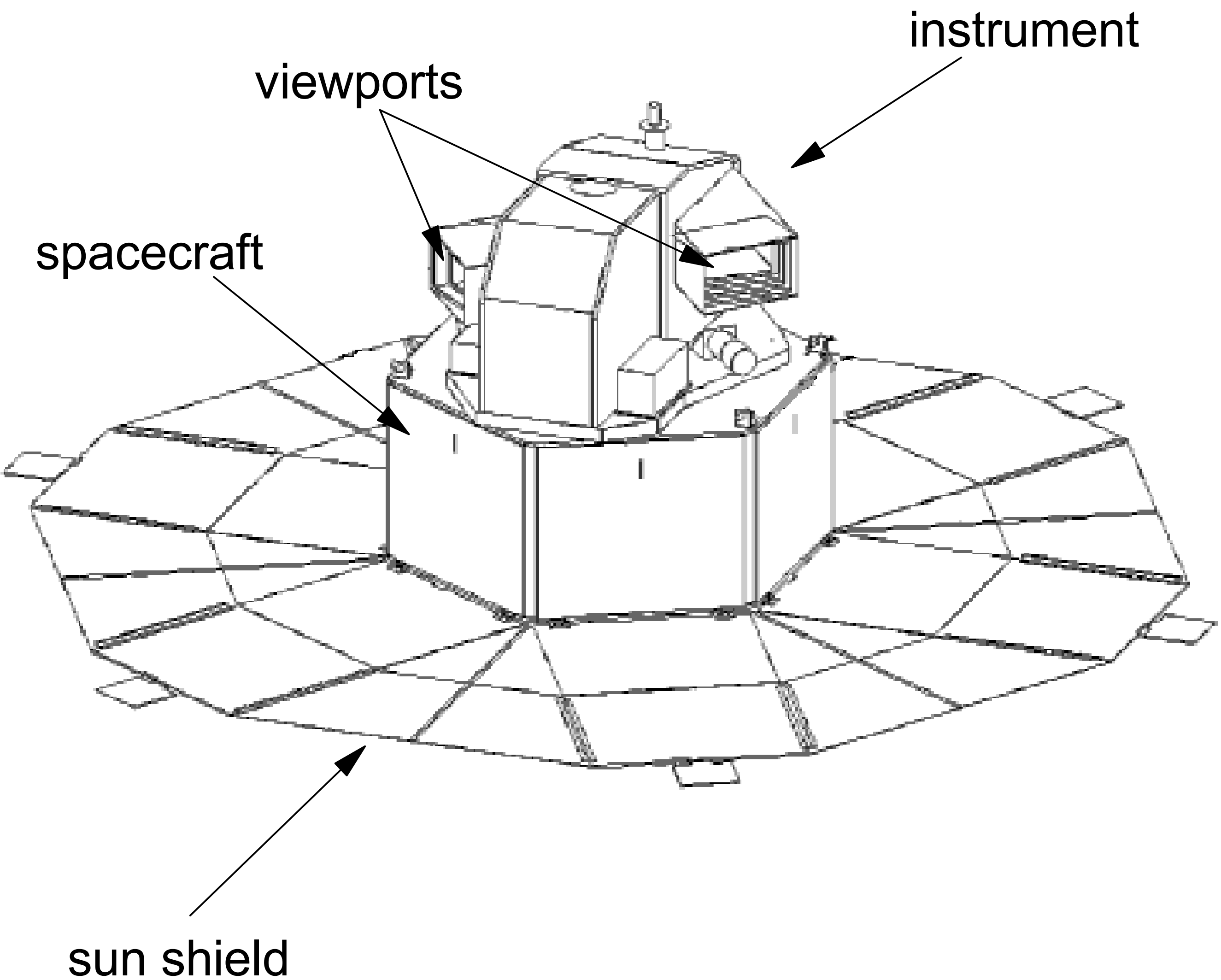
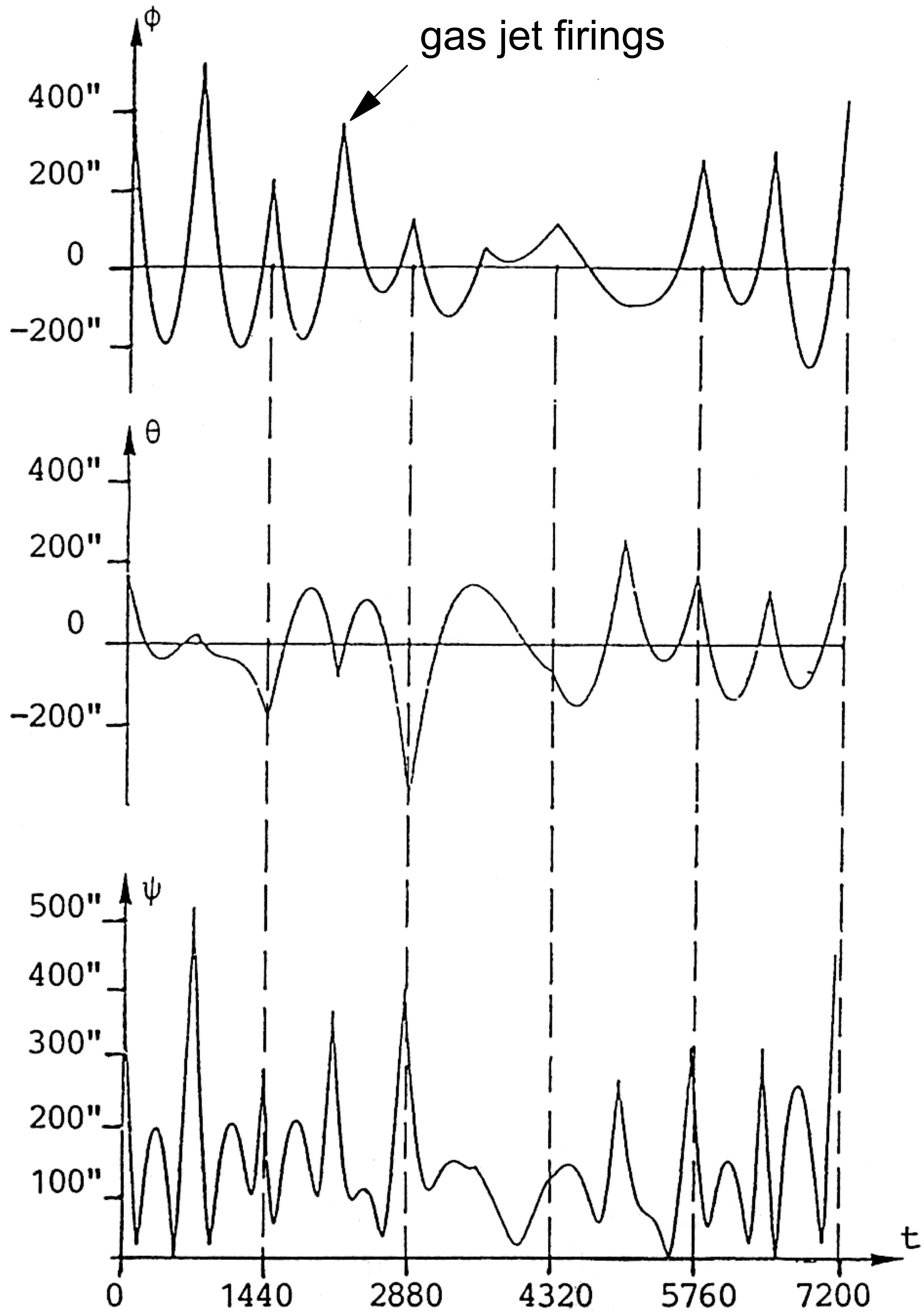
FAME Spacecraft, Shield, and Instrument

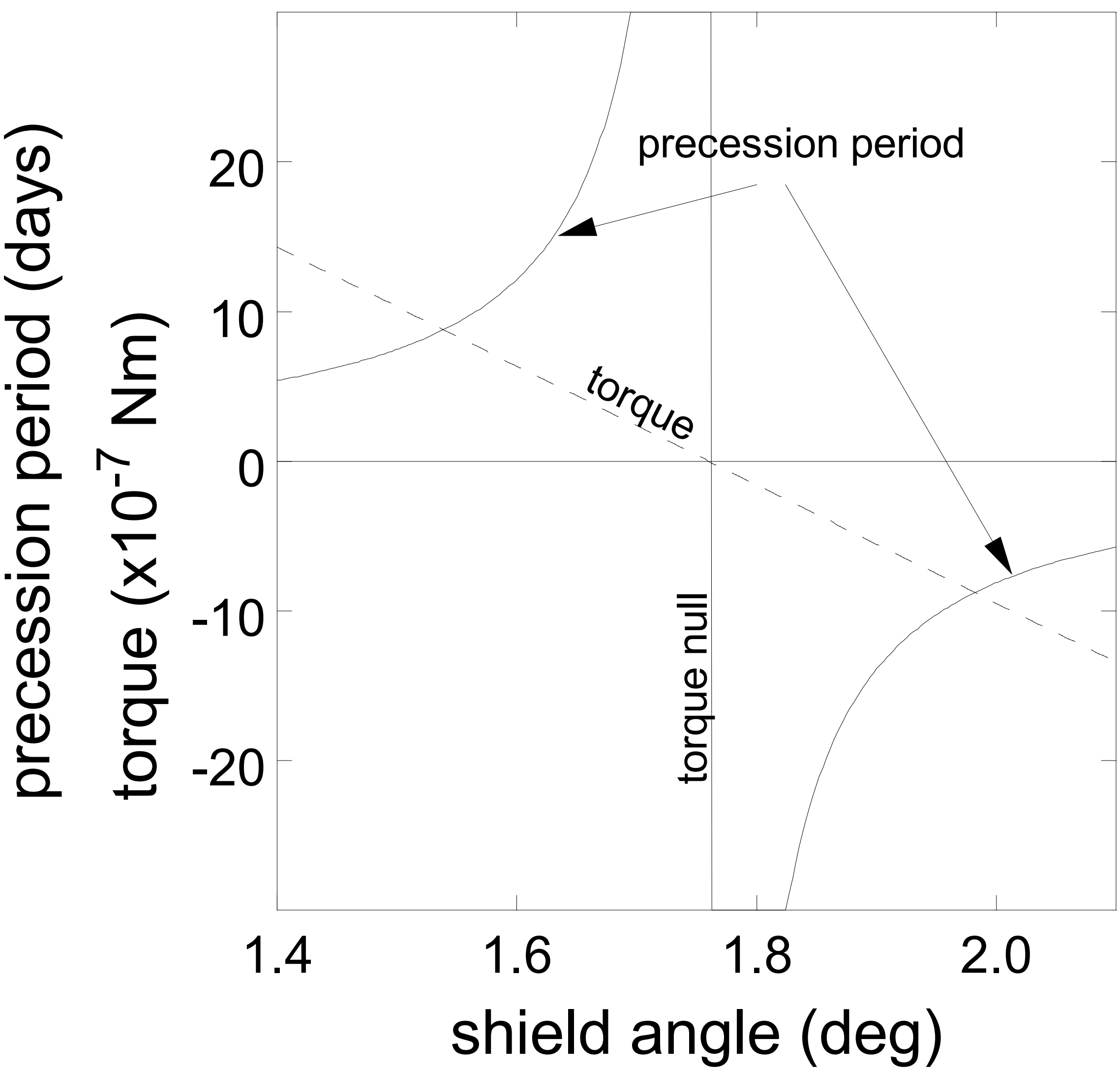


Effect of Thruster Firings

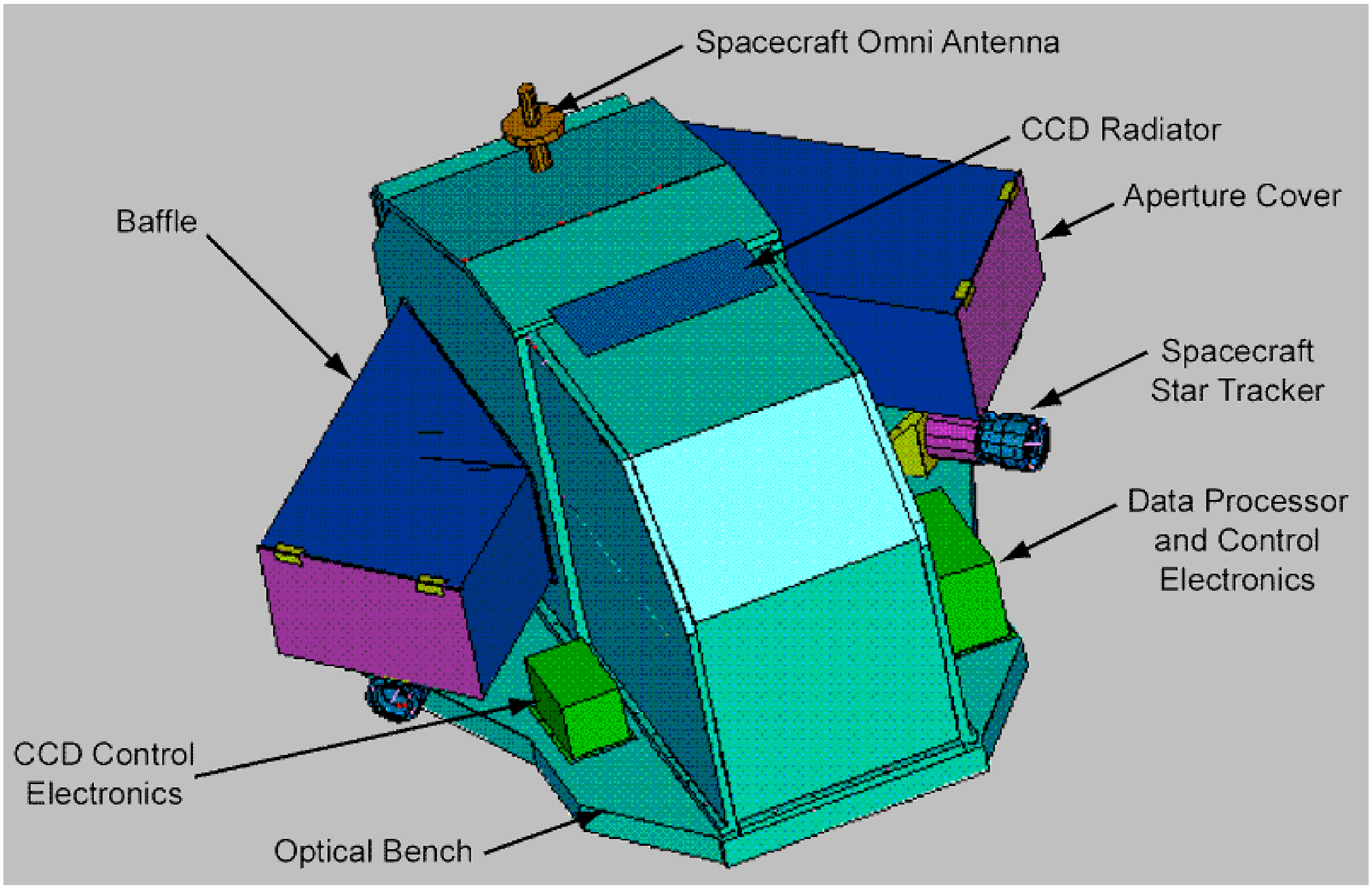
- Hipparcos Attitude Corrections



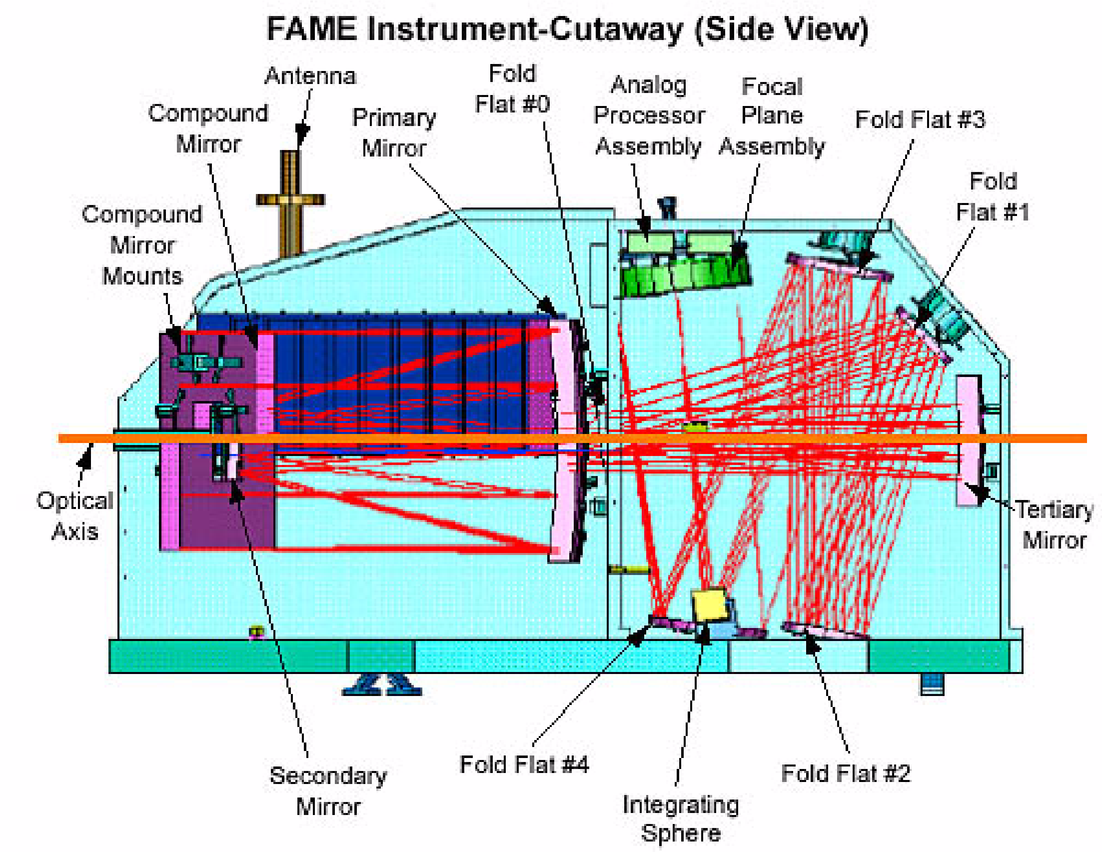
Precession Period as Function of Shield Angle



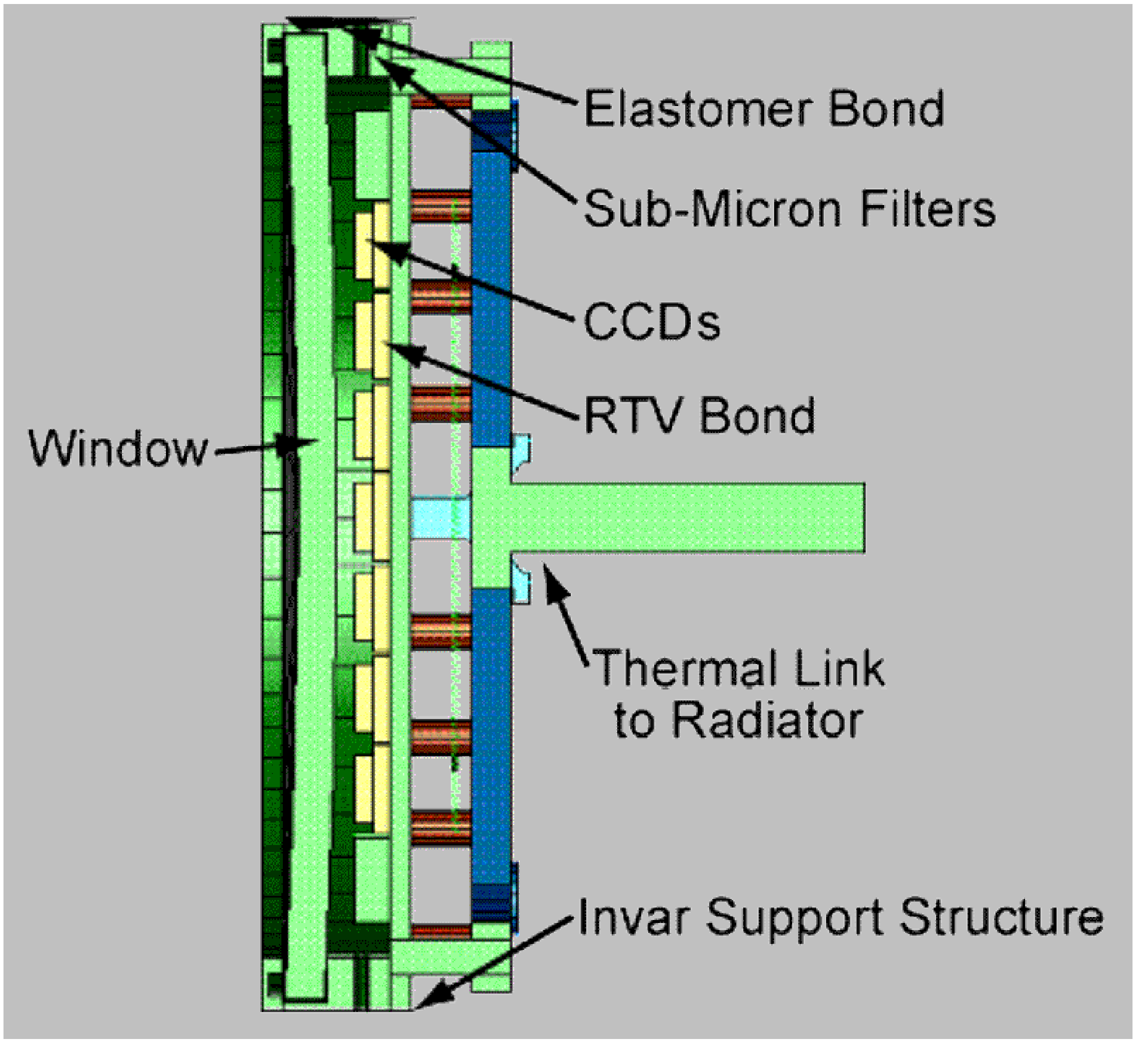
The FAME Instrument Housing



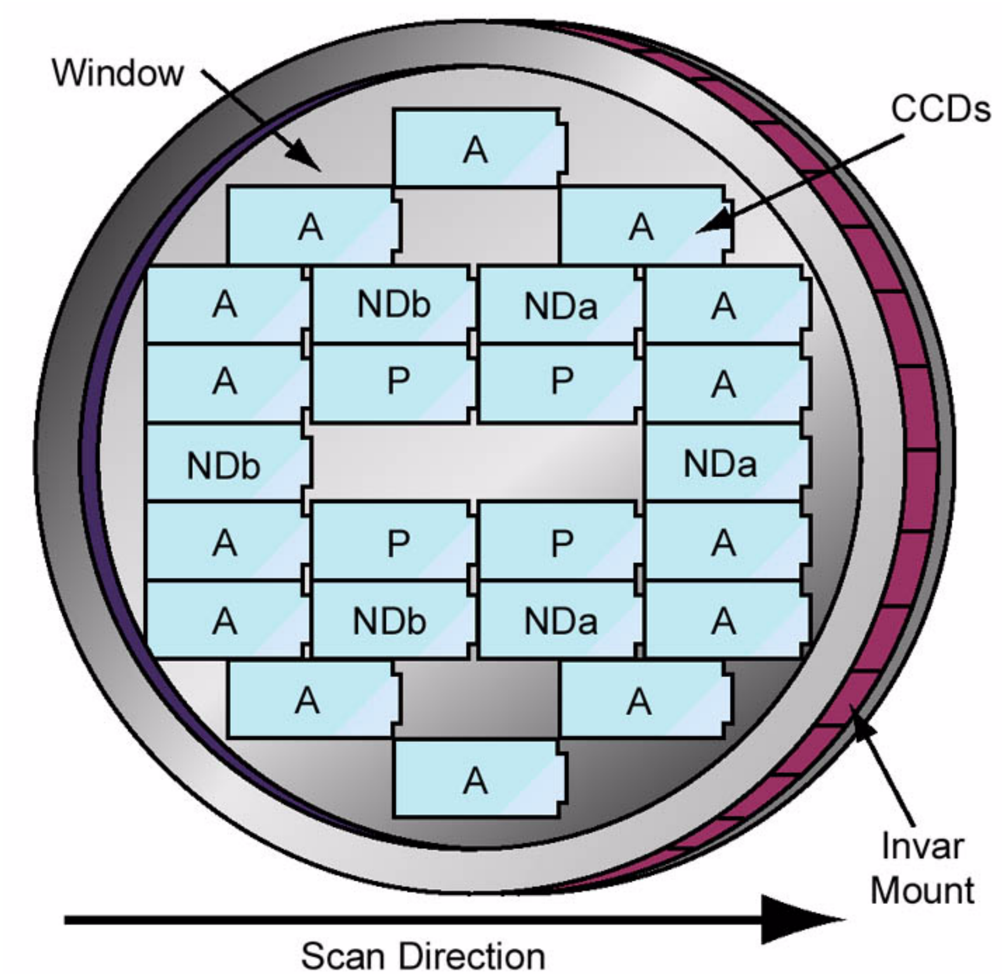
The FAME Instrument



Focal Plane Assembly (side view)



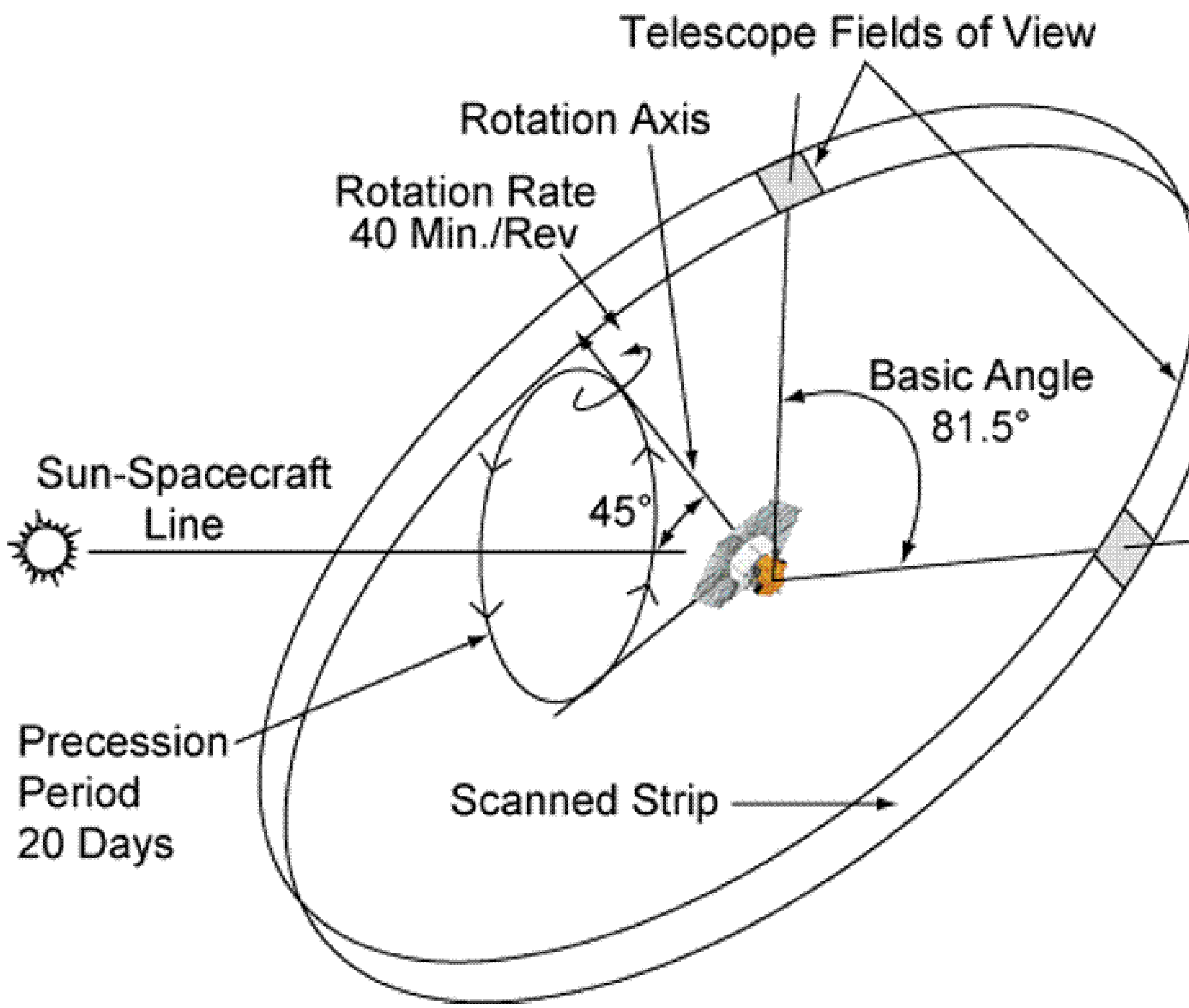
Focal Plane



A-Astrometric
P-Photometric
NDa - Neutral Density Type A
NDb - Neutral Density Type B

FAME Observation Geometry

- Radiation pressure on the sun shield drives the precession



Pause...

- If you get the sense that this is a complicated system, then you are right
- However, we believe all the problems are treatable — you just have to be careful and thorough

FAME: What's it all about?

- It's all about *me*!
- No, it's all about errors!
- No, it's all about **systematic errors**!
  - Least squares fit (nonlinear) of **observables** to model parameters
  - Must model (and remove from data) all perturbations that affect the observables and are important
  - Known physical mechanisms $\longrightarrow$ model parameters
  - Unaccounted-for mechanisms $\longrightarrow$ bias parameters
    - Fourier series, polynomials, etc.

$$\varphi(t) = \sum_{m=0}^{N} A_m P_m(t)$$

polynomials (Fourier, Legendre, etc.)

coefficients

- FAME Observables
  - Scan-direction timing
    - star drops off end of CCD
    - precision ~ 0.5 mas
  - Cross-scan position
    - precision ~ 5 mas

Perturbations of the Observables

- Fundamental goal: accurately connect the observables to positions (stars) on the sky
- Perturbations that affect the connection infiltrate via two paths:
  - Optical path
    - optical surface errors, misalignments, etc.
    - temperature gradient variations
  - Mechanical platform
    - CCDs
    - focal plane mounting
    - optical bench
    - instrument mounting
    - temperature gradient variations
    - spacecraft rotation
- These perturbations that affect the connection fall into three broad categories:
  - Spacecraft rotation (i.e., spin dynamics)
  - Focal plane assembly
  - Instrument optics

Perturbations — Spin Dynamics

- Fuel sloshing
- Earth radiation pressure
  - visible
  - infrared
  - variability due to weather
  - complicated torques
    - spacecraft not protected by shield
    - optical ports
- Variability of solar "constant"
  - variation ~ 0.1 percent
  - T ~ days
  - some evidence for variations on the order of minutes
- Shield & flattop albedos
  - variable over time as materials age
  - spatial inhomogeneities
- Eclipses

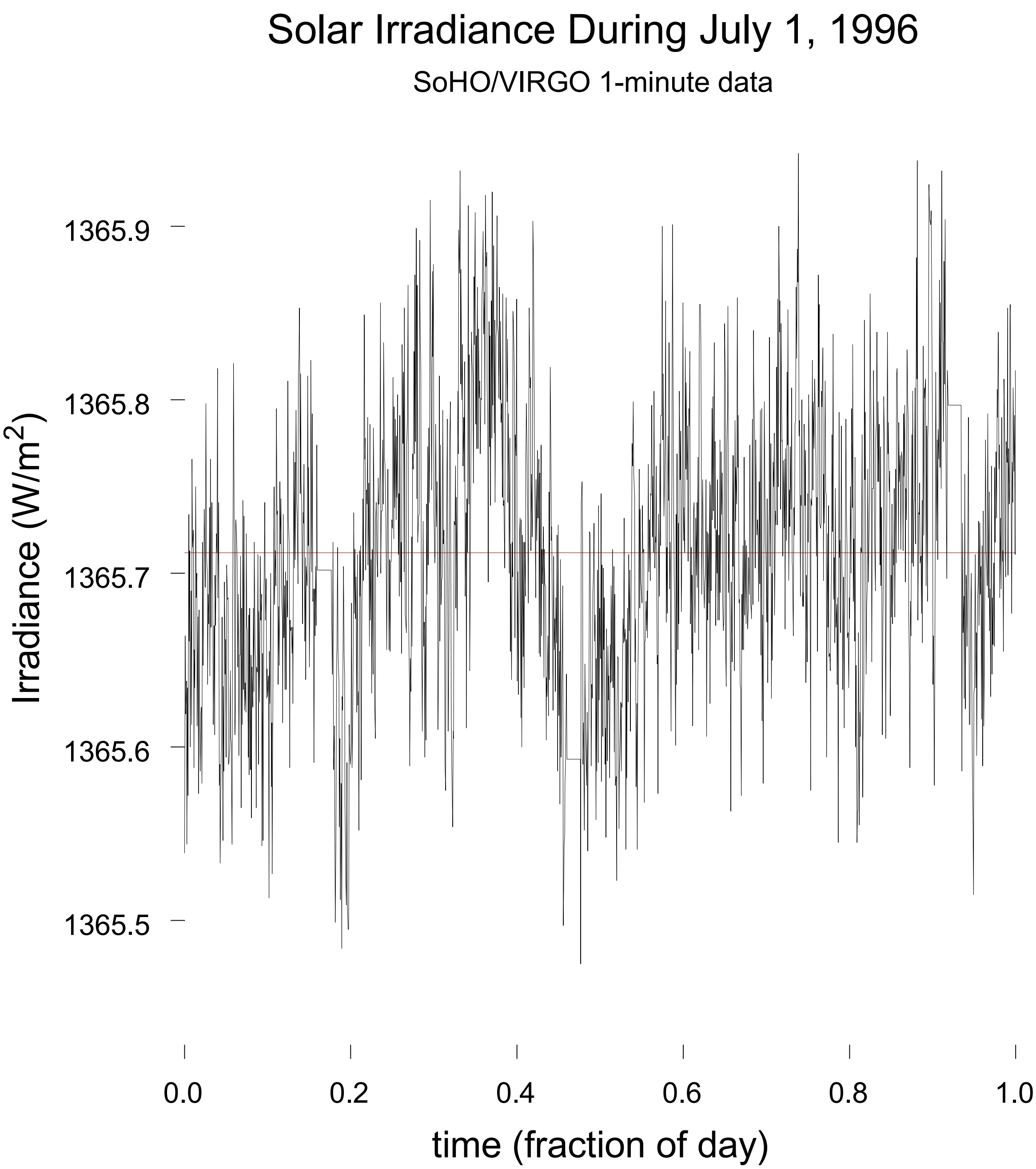
Perturbations — Spin Dynamics (continued)

- Variations in shield angle
  - nonuniform in circumference
  - slow variation over time
  - fast variation — flapping (eclipses)
- Axis of shield misaligned with spacecraft spin axis
- Geotail particle bursts
  - "wind" gusts
  - potentials across spacecraft surfaces $\rightarrow$ currents $\rightarrow$ magnetic torques
    - caused Echo spinup
- Circulation of Sun around rotating frame stationary point
- Variation of solar radiation pressure as spacecraft orbits around the Earth
- Gravity gradient spin modulation
- Magnetic torques

Perturbations — Spin Dynamics (continued)

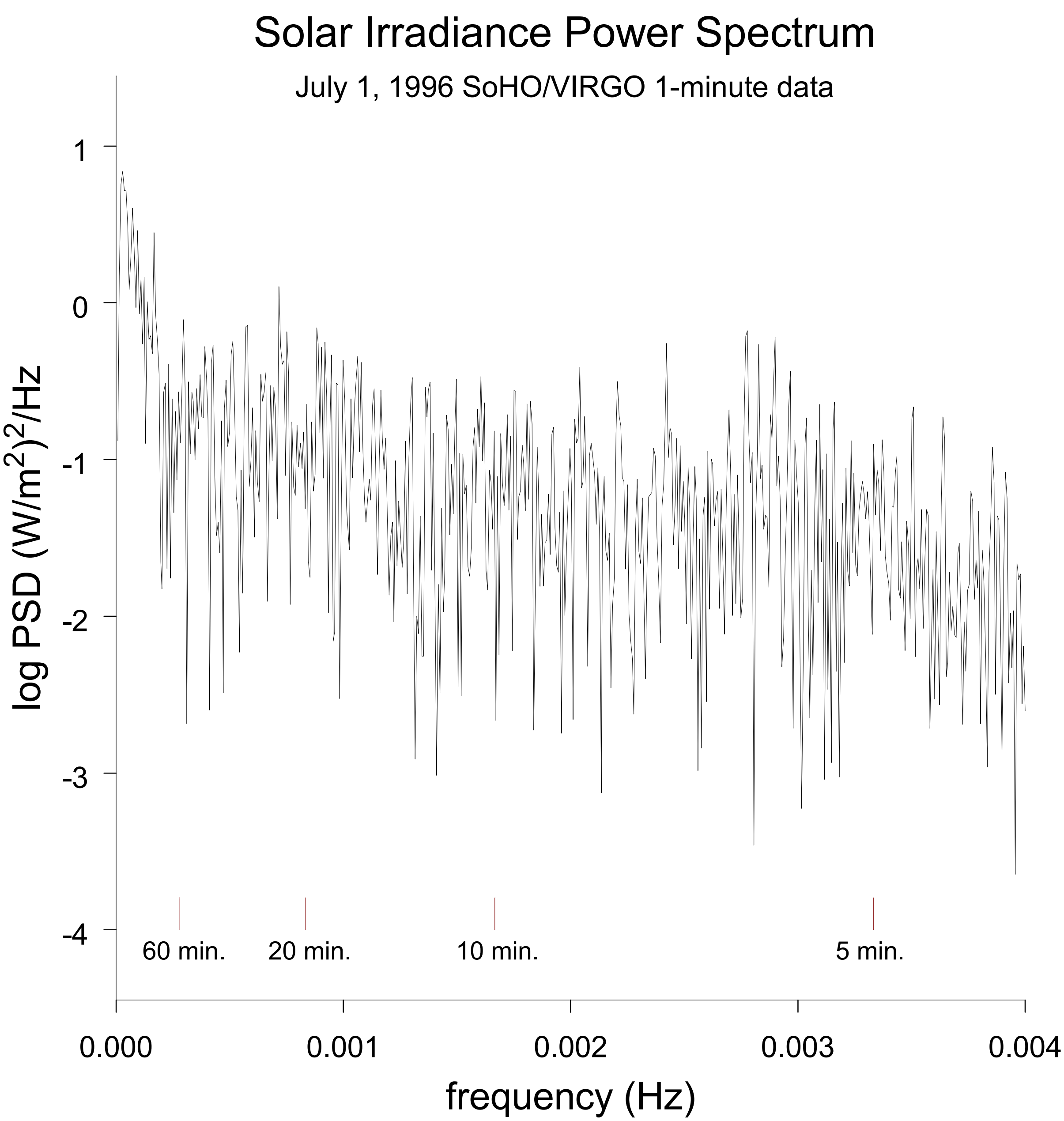
- Magnetopause crossings
  - rare
  - short duration (~15 min) exposure to solar wind

Solar irradiance input



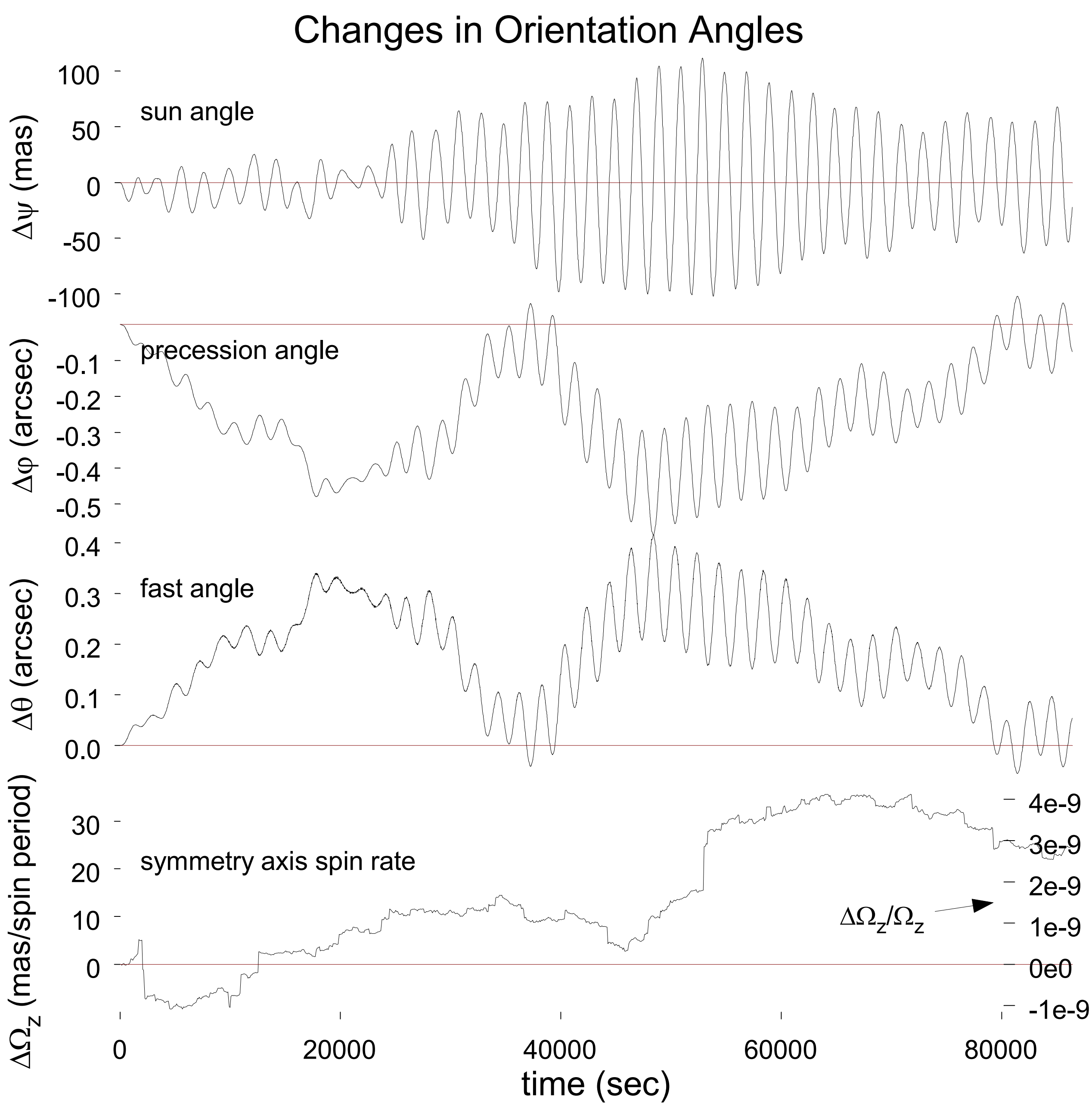
Solar irradiance input

- Note the real power at all frequencies



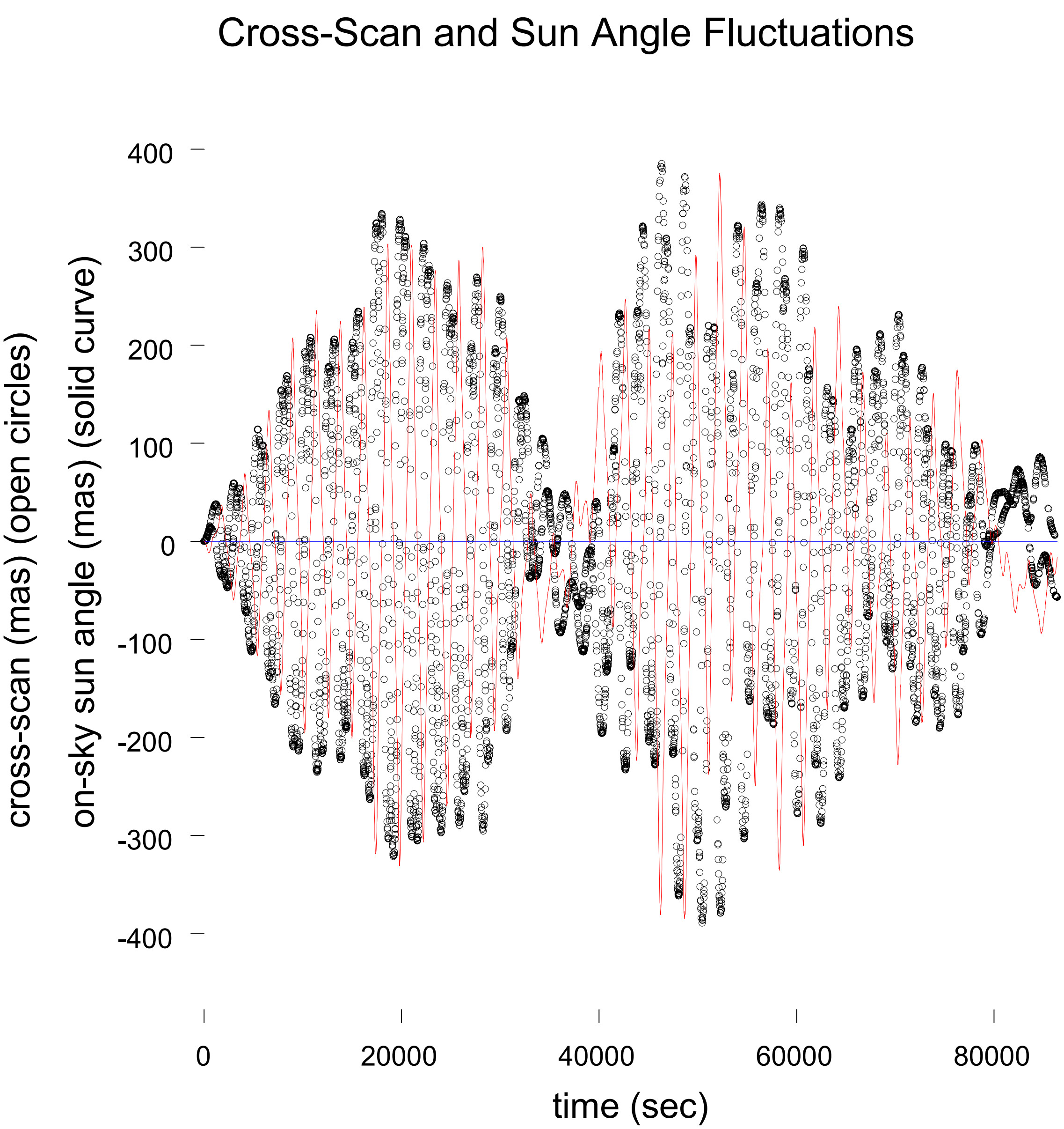
Solar irradiance fluctuation effects on spacecraft attitude

- Orientation changes due to irradiance fluctuations
  - fast angle (θ) and precession angle (φ) changes are opposite in sign
  - spin parallel to symmetry axis (Ω_z) is conserved



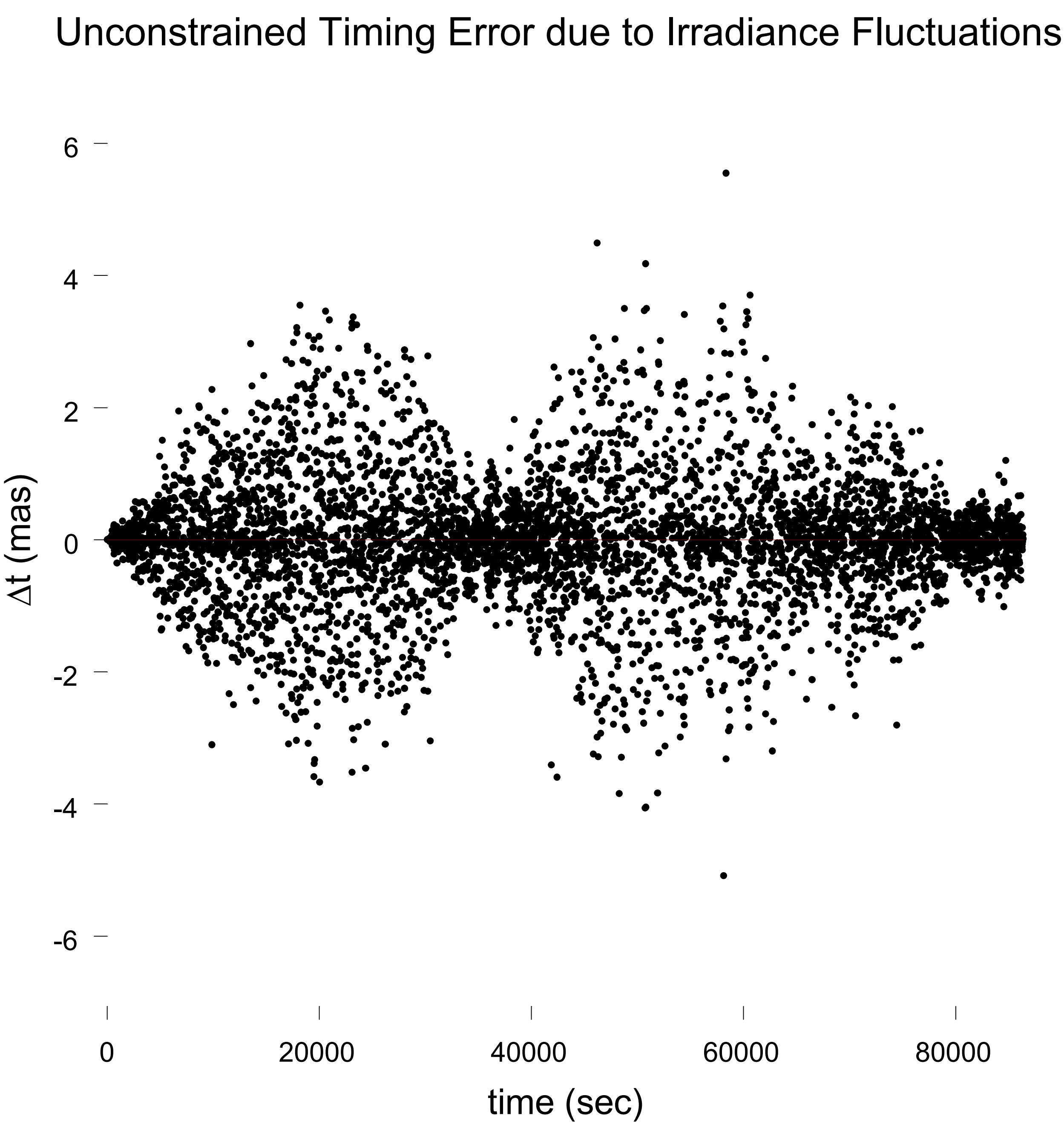
Simulated Observations

- Cross-scan and sun angle (rotation of CCD on plane of sky) perturbations as a function of time



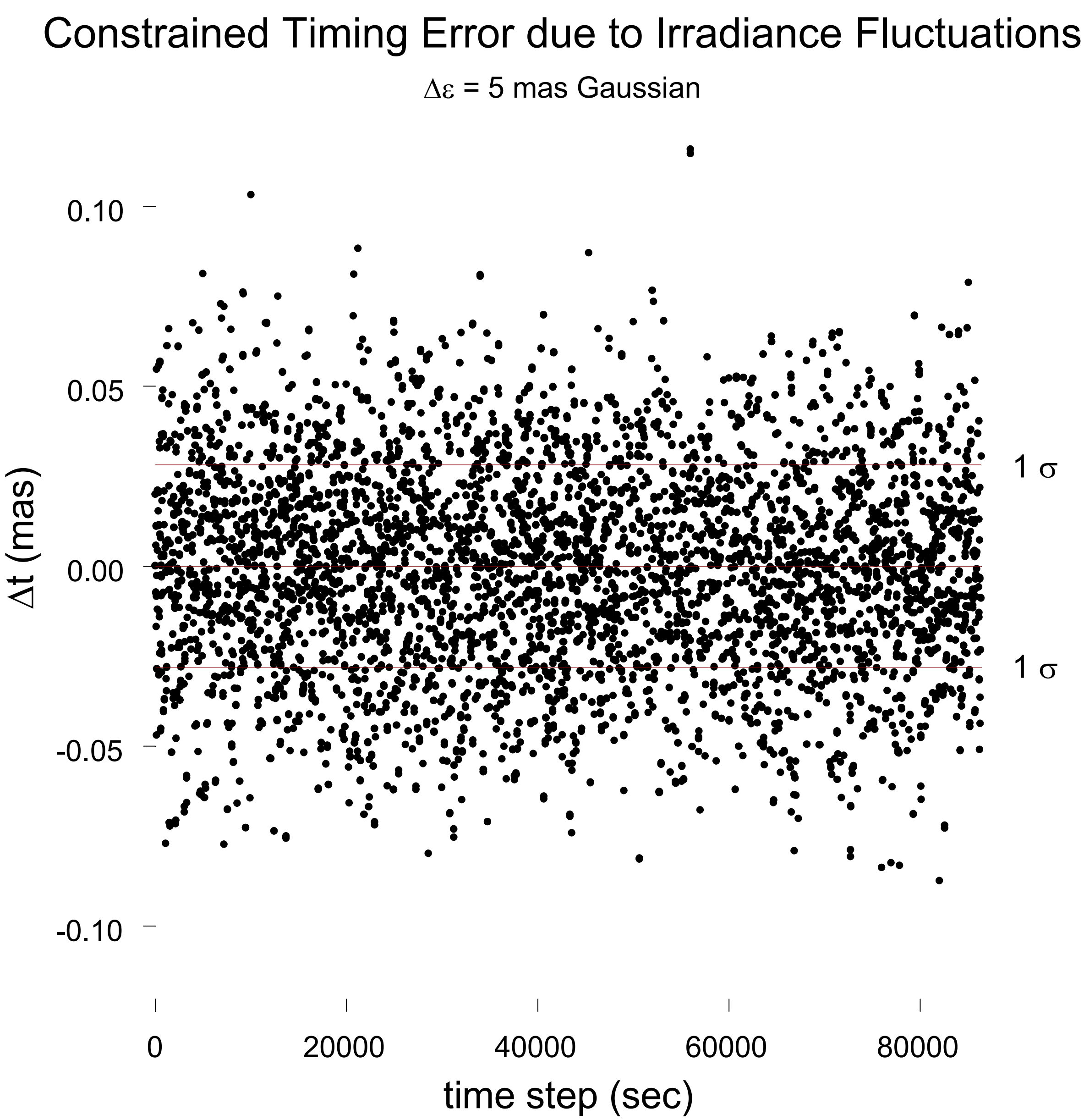
Simulated Observations (continued)

- Single-port timing fluctuations



Simulated Observations (continued)

- Two-port timing fluctuations



Perturbations — Focal Plane Assembly

- CCD mountings
  - Misalignments (rotation, tilting)
  - Temperature gradient variations
- CCD imperfections
  - columns not straight
  - potato chipping
  - how well do we know that last row?
- FPA misalignment

Perturbations — Instrument Optics

- All optical elements:
  - Aberrations
    - Classical
    - Diffraction (also classical, but not as well known)
  - Defocus
  - Static misalignments
    - Manufacturing errors
    - Baggage handling gorillas
    - Launch vibration
  - Time-variable misalignments
    - Temperature gradient variations
- (Don't forget the FPA window)

Outline of FAME Data Reduction

- Each known significant perturbation mechanism will have to be modeled, including both the known physics AND bias terms:

$$\varphi(t) = F\left(t;\vec{\lambda}\right) + \sum_{m=0}^{N} A_m P_m(t)$$

physics

model parameters

bias parameters

- Goal of least squares: minimize a merit function, usually chi-squared,

$$\chi^2 = \sum_{i=1}^{N} \frac{1}{\sigma_i^2}[\tilde{\varphi}(t_i) - \varphi(t_i)]^2$$

- Taking partial derivatives of χ^2 wrt the parameters yields the normal equations, which can be solved for the best-fit parameter values

- (Actually, we perform a nonlinear least squares analysis, which requires iteration, but the basic principle is the same)

Outline of FAME Data Reduction (continued)

- FAME data reduction will be accomplished in three stages:
  - Observing spiral reduction
    - Goal: model of spacecraft rotation
    - Timescale: several rotations to perhaps a day or two
  - Global fit
    - Goal: tie together the observing spirals to yield a single, global, model of the spacecraft rotation
    - Timescale: >3 months
  - Astrometric parameter determination
    - Goal: astrometric catalog
    - Timescale: mission
    - Iterate (if necessary)